ate cultivar selected. If nematode population densities are high, a combination of fertilization and application of Nematrol may provide acceptable control of damage associated with root-knot nematode in tomato and basil crops.

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Economic Analysis of Sustainable Agricultural Cropping Systems for Mid-Atlantic States

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ABSTRACT. This paper evaluates the profitability and economic risks associated with four cropping systems for the Sustainable Agriculture Demonstration site at Beltsville, Maryland, for the 1994-97 period. Each system follows a 2-year rotation of corn in the first year and winter wheat and soybean in the second year. The four systems are (1) a *no-tillage* system with recommended fertilizer and herbicide inputs, (2) a no-tillage system with *crownvetch* living mulch, (3) a no-tillage system with winter annual *cover crop*, and (4) a reduced tillage *manure-based* system without chemical inputs. The cover crop system is the most profitable ($238 in gross margin), closely followed by the no-tillage ($233) and the manure-based system ($217). Even though farmers desire a cropping system that maximizes profits, the variability of profits, or risks, can influence the desirability of the cropping system. In terms of risks, no-tillage is the most preferred rotation with the smallest coefficient of variation (1.14) followed by the cover crop system (1.24), the manure-based system (1.58), and the crownvetch system (5.45). The same ranking can be obtained using a "safety-first" criterion for risk-averse farmers, in which the gross margin of the no-tillage system would exceed $53 ha^{-1} in three out of four years, while the gross margin of the cover crop system would exceed $39 ha^{-1} in three out of four years. The manure-based system is an organic system and it was not profitable in 1996 and 1997 because of weed infestations. However, the manure-based system shows potential to be the most profitable if some methods can be found to control weeds without resorting to

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KEYWORDS. No-tillage, crown vetch, cover crop, manure, cost, returns, gross margins, risks

INTRODUCTION

In Mid-Atlantic states, most crops are grown on fields with steep slopes and soil erosion is a major threat to long-term productivity of agricultural lands. Reduced tillage helps reduce soil erosion. However, reduced-tillage systems often require more chemical fertilizer and herbicide inputs than conventional tillage and thus result in greater potential for water pollution. Therefore, the agricultural research community is challenged to develop profitable cropping systems that incorporate reduced tillage as well as reduced dependence on fertilizer and herbicide inputs.

Profitability is a major concern for farmers when they evaluate the sustainability of alternative cropping systems. A sustainable agricultural system must provide farmers with adequate profits. Otherwise, few farmers will adopt the sustainable system even if it is beneficial to the environment and to the natural resource base. Economic risks is also a major consideration when selecting a sustainable cropping system, and farmers respond to risks in different ways. Risk neutral farmers will select the cropping system that generates the largest expected (average) profit without regard to variability of profits, while risk averse farmers will accept smaller profits in exchange for more stable profits.

Several studies have been conducted to compare the economic impacts of conventional farming systems with those of alternative farming systems. However, the relative profitability of alternative systems to conventional systems is inconclusive. Ott and Hargrove (1989) evaluated the profitability and economic risks of using different cover crops (crimson clover, hairy vetch, winter wheat, and winter fallow) in no-tillage corn production based on three years of data from an agronomic cover crop experiment in Georgia. The authors used safety first criteria to identify cover crop strategies for farm operators with different risk attitudes. The authors found that no-tillage corn following hairy vetch generated the largest average profit. The authors also found that hairy vetch with 56 kg ha^{-1} N applied was the best strategy for risk-neutral farmers and hairy vetch with no N applied was preferred by risk-averse farmers. Hanson et al. (1993) conducted a 3-year field study in the Maryland Coastal Plain and Piedmont to assess the agronomic and economic characteristic of a hairy vetch cover crop on no-tillage corn. Their results indicated that at the corn price of \$94.50 MT^{-1}, corn following hairy vetch with additional 135 kg ha^{-1} N was the most profitable system in the Coastal Plain and corn following winter fallow with additional 45 kg ha^{-1} N was the most profitable system in the Piedmont. Using the safety-first criterion, the authors found that a hairy vetch cover crop system was the most desirable choice for risk averse farmers in both locations.

In South Dakota, Smolik et al. (1995) conducted two studies comparing the agronomic, economic, and ecological performance of alternative, conventional, and reduced-tillage farming systems over a 7-year period. Study I compared profitability of alternative, conventional, and ridge till farming systems. The alternative system consisted of a 4-year oats/alfalfa/soybeans/corn rotation with no chemical fertilizer and pesticide inputs. The conventional and ridge till systems each consisted of 3-year corn/soybeans/spring wheat rotations with recommended chemical fertilizer and pesticide inputs. The moldboard plow was used in the conventional system. In Study II, the alternative system consisted of a 4-year oats/clover/soybeans/spring wheat rotation with no commercial chemical and pesticide inputs. The conventional and minimum tillage farming systems each consisted of 3-year rotations of soybeans/spring wheat/barley with recommended chemical fertilizer and herbicide inputs. Only the conventional system used the moldboard plow. In Study I, the results indicated that the alternative system had the largest net returns, followed by the conventional and the ridge till systems. In Study II, the conventional system had slightly larger net income than the alternative system. The minimum tillage system was the least profitable.

In Iowa, proponents of alternative agriculture suggest that certain sustainable cropping systems can reduce soil erosion and water pollution without adversely affecting farmers' incomes. Producers are urged to use a legume crop in a rotation with row crops such as corn and soybeans. Foltz et al. (1993) assessed the economic and environmental implications of selected eastern Corn Belt farming systems using output from two process simulation models, EPIC and GLEAMS, combined with a farm level linear programming model. The results indicated that an alfalfa based cropping system was generally less profitable than a corn soybean rotation. Net returns were projected to decline by about 38 percent if alfalfa was included in an eastern Corn Belt cropping system.

Martin et al. (1991) used a linear programming model to determine relative profitability of crop rotations and weed management systems for three different farm sizes under alternative tillage systems. Their results showed that net incomes for no-tillage systems on all farms were consistently lower

than those for moldboard and chisel plow tillage systems, because of slightly smaller yields and substantially higher herbicide costs.

Concerns that conventional agriculture may pollute the environment and harm the natural resource base have prompted the Beltsville Agricultural Research Center to initiate several sustainable agricultural projects in Beltsville, Maryland. One of the major projects is the 6-ha Sustainable Agricultural Demonstration site on the South Farm, which has been designated to evaluate the efficacy of sustainable agricultural strategies that are compatible with reduced-tillage systems. The objective of this paper is to evaluate the profitability and economic risks associated with different cropping systems used in the Sustainable Agriculture Demonstration site.

MATERIALS AND METHODS

Site Description

The Beltsville Sustainable Agriculture Demonstration site was established on a 6-ha site with 2 to 15% slope on the South Farm of the Beltsville Agricultural Research Center. Five soil types were identified on this site: (1) coarse-loamy to loamy skeletal Typic Hapludult, (2) coarse-loamy Typic Hapludult, (3) fine-loamy Typic Hapludult, (4) fine-loamy to coarse-loamy Aquic Hapludult, and (5) coarse-loamy to fine-loamy Aeric or Typic Endoaquult (M. Rabenhorst, University of Maryland, personal communication). A corn-soybean rotation was used on the field for at least five years prior to establishment of the experimental plots.

Thirty-two plots, 9 m wide and approximately 150 m long, were established on a contour across the slope of the field and were separated by 2 m grass strips. Plots were laid out in the fall of 1992 and rotations were initiated in 1993. The first complete year of each cropping system began in the fall of 1993 with establishment of wheat and cover crops. Four cropping systems were established. Each cropping system followed a two-year rotation with corn in the first year and wheat/soybean double crop (with variations as noted below) in the second year. Corn was generally planted in early May, wheat in late October, and double-crop soybean in early July. Full-season rather than double-crop soybeans were planted in late May in one of the cropping systems.

The experimental design was a randomized complete block with four blocks. Each block contained four cropping systems assigned permanently to two plots. Plot pairs alternated between the corn and wheat/soybean phases of the rotation so that both phases of the rotation were present in every year for each cropping system.

DESCRIPTION OF CROPPING SYSTEMS

The four cropping systems established on the Sustainable Agriculture Demonstration site were developed with the expectation that (1) at least one grain crop would be harvested in every year, (2) crops would be rotated, (3) soil would be covered with vegetation during as much of the rotation as possible, and (4) tillage would be minimized. The no-tillage system with recommended inputs is representative of a typical system farmers in the mid-Atlantic states would use on highly erodible soils. The other systems employ alternative systems that may improve sustainability but that are not typically practiced in this area at present.

The no-tillage system represented recommended practices for no-tillage grain production in the mid-Atlantic states. Every planting provided a harvested crop with the intent of maximizing grain production during the two-year rotation. The absence of tillage and the presence of high residue level protected the soil against erosion. Fertilizer management followed the University of Maryland FERTREC program and herbicide applications were made according to University of Maryland recommendations. Postemergence herbicides were applied according to a zero-threshold philosophy so as to prevent weed seed production and reduce the weed seed bank.

The crownvetch system followed similar guidelines to the no-tillage system except that crops were grown in a perennial crownvetch living mulch. Crownvetch was planted at 5.6 kg ha^{-1} after wheat harvest in the first two years and allowed to establish during the remainder of those years rather than growing double-crop soybeans. The crownvetch was suppressed but not killed by herbicides applied before each crop. This living mulch was expected to reduce erosion and improve soil tilth and fertility.

The cover crop system used the winter annual species hairy vetch before corn and wheat before soybean. Since there was insufficient time to plant hairy vetch following a wheat/soybean double crop, a full-season soybean crop was grown between May and September to permit time to plant hairy vetch in October. Crops were planted into cover crops without tillage. Cover crop residues were expected to protect soil from erosion, improve soil moisture retention, and suppress early-season weed emergence. As a result preemergence herbicides were eliminated and only postemergence herbicides were used as needed. In addition, hairy vetch is a legume and fixes atmospheric nitrogen for use by subsequent crops (Hanson et al., 1993). Thus hairy vetch was expected to provide nitrogen for corn, so preplant nitrogen application was eliminated. Only planter and sidedress nitrogen were applied.

The manure-based system is an organic system that eliminated all fertilizer, insecticide, and herbicide inputs. Cow manure provided nutrients for corn and wheat according to the University of Maryland MANUREC program.

Crimson clover was overseeded into soybeans at last cultivation and provided additional green manure for corn. Manures were incorporated by chisel plowing and disking before planting. Weeds were controlled in corn and soybeans by rotary hoeing and cultivating with equipment designed to retain residue on the soil surface.

SOURCES OF DATA

Grain yields were determined by harvesting the middle eight rows of corn, five rows of wide-row soybean, nine rows of narrow-row soybean, and 3.8 m of wheat for the entire plot length and weighing in a weigh wagon. Grain yields were adjusted for moisture content of 15.5% for corn, 13.5% for wheat, and 13.0% for soybean. Wheat straw was baled from the entire plot after harvest.

Crop prices used were annual prices for the period 1994 through 1997 (Maryland Agri-Facts, various years). Since wheat grain was contaminated by wild garlic and could not be sold as milling quality, the annual price for wheat was adjusted to a feed grain price by taking the lesser of either the annual corn price plus \$19.68 MT^{-1} (\$0.50 bu^{-1}) or the annual wheat price. Nominal prices were adjusted to 1993 constant dollars using the Consumer Price Index. The price for wheat straw was held constant at \$105.84 MT^{-1} (\$1.20/25 pound bale) during all years.

The quantities of seeds, fertilizers, and chemicals used were actual values for the demonstration farm, with their respective prices. The typical custom hire charges represent 1993 prices for the state of Maryland (Johnson, 1993) and are used for all years and all blocks. The custom rate charges for 1996, block 1, are presented in Table 1. These charges were assumed to cover labor, machinery operating and depreciation costs, and associated insurance and taxes. Custom hire charges were used instead of breaking down individual operations and costing the components. Arguments can be made both that these charges underestimate and overestimate actual costs to farmers. Farmers' out of pocket costs cannot be determined from these charges.

Annual production costs for 1996, block 1, for the four cropping systems are detailed in Table 2. Seed, fertilizer, and chemical costs were provided by Johnson (1993) and are indicative of costs faced by farmers in 1994. Operating interest is for 6 months at an annual rate of 12%. Total variable production costs for each rotation are calculated as the simple average of the two rotation components (corn and wheat/soybean/straw), assuming that half the area is planted to each component. It is assumed that the farmer has both crop and livestock production and thus there is no cost for manure.

TABLE 1. Custom rate charges (\$/ha), 1996, Block 1.

			No-tillage		Crown vetch		Cover crop		Manure	
	units	price (\$)	amt	\$/ha	amt	\$/ha	amt	\$/ha	amt	\$/ha
CORN										
Spread manure	MT	2.21							21.28	47.03
Apply lime (incl. lime)	MT	26.40			0.28	7.39				
Spread fertilizer	ha	12.35	1	12.35	1	12.35	1	12.35		
Sidedress N	ha	14.80	1	14.80	1	14.80	1	14.80		
Chisel plow	ha	29.65							1	29.65
Disk	ha	24.70							2	49.40
Plant, no-till	ha	29.65	1	29.65	1	29.65	1	29.65	2	59.30
Plant hairy vetch, no-till drill	ha	37.00					1	37.00		
Overseed	ha	13.60							1	13.60
Spray	ha	12.35	1	12.35	2	24.70	1	12.35		
Rotary hoe	ha	19.80							1	19.80
Flail mow	ha	29.64					1	29.64		
Cultivate	ha	19.80							3	59.40
Combine	ha	61.75	1	61.75	1	61.75	1	61.75	1	61.75
Drying grain	MT	9.85	8.3	81.79	11.14	109.73	7.569	74.56	4.412	43.46
Hauling grain	MT	3.95	8.3	32.80	11.14	44.00	7.569	29.90	4.412	17.43
Total Custom Hire for Corn				\$245.49		\$304.38		\$301.99		\$400.82
WHEAT/SOYBEAN/HAY										
Spread manure	MT	2.21							16.8	37.13
Apply lime (incl. lime)	MT	26.40	0.56	14.78	1.68	44.35	2.24	59.14		
Spread fertilizer	ha	12.35	1	12.35	1	12.35	1	12.35		
Chisel plow	ha	29.65							2	59.30
Disk	ha	24.70							2	49.40
Plant wheat, drill	ha	24.70							1	24.70
Plant wheat, no-till drill	ha	37.00	1	37.00	1	37.00	1	37.00		
Plant soybeans, no-till	ha	37.00	1	37.00	1	37.00	1	37.00		
Plant soybeans, conventional	ha	29.65							1	29.65
Spray	ha	12.35	3.5	43.23	3	37.05	1	12.35		
Cultivate	ha	19.80							2	39.60
Combine	ha	61.75	2	123.50	2	123.50	1	61.75	2	123.50
Hauling grain	MT	3.95	5.59	22.07	6.175	24.39	3.93	15.50	4.877	19.27
Rotary mow	ha	29.64	1	29.64	1	29.64	1	29.64		
Flail mow	ha	29.64					1	29.64		
Bale straw	bale	0.35	193	67.43	185.3	64.84			108.7	38.04
Haul straw	bale	0.25	193	48.17	185.3	46.31			108.7	27.17
Total Custom Hire for Wheat/SB				\$435.16		\$456.43		\$294.37		\$447.75

RESULTS AND DISCUSSION

Yield Analysis

Weather was the major cause of yield variability over time. The weather conditions for 1994-1997 were extremely variable. In general, during 1994 and 1996 when uniform rainfall fell throughout the growing season, crop

TABLE 2. Production costs, 1996, Block 1.

			No-tillage		Crown vetch		Cover crop		Manure	
	units	price ($)	amt	$/ha	amt	$/ha	amt	$/ha	amt	$/ha
CORN										
Seed: corn	1000	0.90	64.96	58.46	64.961	58.46	64.96	58.46	133.1	119.80
hairy vetch	kg	0.59					28	16.62		
crimson clover	kg	0.95							22.4	21.32
Total Seed Costs				$58.49		$58.46		$75.09		$141.12
Fertilizer: N	kg	0.55	182.6	100.61	182.59	100.61	106.4	58.64		
P	kg	0.55	56.00	30.86	58.81	32.40	63.0	34.72		
K	kg	0.35	123.2	43.50	92.42	32.62	67.2	23.73		
Total Fertilizer Costs				$174.97		$165.64		$117.08		$0.00
Chemicals: Bicep	liter	9.51	5.606	53.31	5.606	53.31				
Gramoxone Ex	liter	9.56	1.752	16.75	1.752	16.75				
Accent	ml	0.94			48.7	45.78	48.7	45.78		
Banvel	liter	25.37					0.58	14.71		
Weedar64	ha	4.94	1	4.94						
Dual	liter	17.36								
Prowl	liter	7.30								
Surfactant	liter	4.40	0.73	3.21	1.46	6.42	0.73	3.21		
Total Chemical Costs				$78.21		$122.26		$63.70		$0.00
Custom hire				$245.49		$304.38		$301.99		$400.82
Operating interest (12% p.a.)				$52.13		$59.83		$48.82		$40.98
Total Variable Costs per ha				$609.26		$710.57		$606.69		$582.92
WHEAT/SOYBEAN										
Seed: wheat	kg	0.2600	134.4	34.95	134.424	34.95	134.4	34.95	134.4	34.95
soybean (old variety)	kg	0.3300	234.8	77.50	234.837	77.50			220	72.60
soybean (Roundup Ready)	kg	0.4162					220	91.56		
Total Seed Costs				$112.45		$112.45		$126.51		$107.55
Fertilizer: N	kg	0.55	100.8	55.55	67.21	37.03				
P	kg	0.55	89.76	49.46	115.52	63.65	57.41	31.63		
K	kg	0.35	58.81	20.76	67.21	23.73	86.82	30.65		
Total Fertilizer Costs				$125.77		$124.41		$62.28		$0.00
Chemicals: Harmony Ex	ml	0.43	73.04	31.41	36.54	15.70				
Gramoxone Ex	liter	9.56	1.752	16.75	3.504	33.50				
Dual	liter	17.36	2.336	40.55	2.336	40.55				
Lorox	kg	23.46	2.24	52.55	2.24	52.55				
Roundup	liter	11.89					4.672	55.55		
Poast	liter	29.07	0.88	25.58						
Surfactant	liter	4.40	1.46	6.42	1.46	6.42				
Crop oil conc.	liter	1.42	1.17	1.66						
Total Chemical Costs				$174.93		$148.73		$55.55		$0.00
Custom hire				$435.16		$456.43		$294.37		$447.75
Operating interest (12% p.a.)				$75.69		$73.66		$46.98		$39.77
Total Variable Costs per ha				$923.99		$915.68		$585.69		$595.07
TOTAL VARIABLE COSTS PER HA ROTATION				$766.63		$813.12		$596.19		$589.00

yields for all cropping systems were higher than those in the dry years of 1995 and 1997. Drought in 1997 was especially severe; it was the worst drought in the last 50 years.

Corn yields for the four cropping systems from 1994 through 1997 are presented in Table 3a. No single cropping system had the highest average corn yield for all crop years. The cover crop had the highest yields in 1994 and 1997, the crownvetch system had the highest yield in 1996, and no-tillage yielded the highest in 1995. Corn yields for the manure-based system declined considerably in 1996 and 1997 relative to the better yielding treatments because of increased weed competition in those two years. On the average, the cover crop system had the highest average yields followed by no-tillage, crownvetch, and the manure-based system.

Table 3b shows wheat yields for the four cropping systems from 1994 through 1997. The crownvetch system had the highest wheat yields in 1994, 1996, and 1997, but the manure-based system had the highest yield in 1995. Poor wheat yields for the manure-based system in 1996 and 1997 were again due to increased weed competition in those two years. When averaging across years, the crownvetch system had the highest wheat yields, followed by the no-tillage system and the manure system.

TABLE 3a. Corn yields (MT/ha), 1994-97.

	Block	1994	1995	1996	1997	Mean	C.V.
No-tillage	1	10.82	5.06	8.30	2.46	6.66	
	2	10.95	8.12	11.54	4.24	8.71	
	3	11.63	6.71	10.10	2.25	7.67	
	4	11.35	6.61	11.90	3.09	8.24	
	Mean	11.19	6.62	10.46	3.01	7.82	0.49
Crownvetch	1	7.44	3.01	11.14	1.38	5.74	
	2	7.97	2.87	12.31	0.19	5.84	
	3	9.60	4.10	12.55	1.07	6.83	
	4	9.40	4.53	12.69	2.71	7.33	
	Mean	8.60	3.63	12.17	1.34	6.44	0.76
Cover crop	1	10.91	6.72	7.57	5.34	7.64	
	2	11.92	7.32	11.45	5.26	8.98	
	3	12.21	6.39	9.51	2.85	7.74	
	4	11.24	4.40	10.69	2.05	7.10	
	Mean	11.57	6.21	9.80	3.88	7.86	0.46
Manure	1	7.71	6.49	4.41	2.26	5.22	
	2	9.04	5.50	6.31	0.34	5.30	
	3	9.86	6.34	6.85	1.32	6.09	
	4	10.38	6.77	5.91	1.01	6.02	
	Mean	9.25	6.27	5.87	1.23	5.66	0.60

TABLE 3b. Wheat yields (MT/ha), 1994-97.

	Block	1994	1995	1996	1997	Mean	C.V.
No-tillage	1	1.311	3.247	4.001	1.812	2.593	
	2	3.089	3.123	4.511	3.123	3.462	
	3	2.909	4.117	3.455	3.064	3.386	
	4	1.158	4.273	3.710	3.513	3.164	
	Mean	2.117	3.690	3.919	2.878	3.151	0.326
Crownvetch	1	4.248	3.121	4.246	3.790	3.851	
	2	4.090	3.150	4.728	4.310	4.069	
	3	5.224	3.604	4.867	4.590	4.572	
	4	3.759	3.681	4.069	3.640	3.787	
	Mean	4.330	3.389	4.478	4.083	4.070	0.137
Manure	1	3.088	3.324	3.022	1.182	2.654	
	2	3.170	4.279	2.838	1.893	3.045	
	3	3.970	4.931	2.772	2.469	3.536	
	4	3.756	4.683	2.521	1.872	3.208	
	Mean	3.496	4.304	2.789	1.854	3.111	0.353

Yield variability is also important in determining which cropping system to use. Both the standard deviation and the coefficient of variation are commonly used to measure variability, but the coefficient of variation is a better measurement when the means differ considerably. Thus, the coefficient of variation is used to measure yield variability. We used data from each block in each year (16 observations) to determine variability in both space and time. As shown in Table 3a, the cover crop system, which had the highest average corn yield, also had the smallest coefficient of variation (0.46), followed by the no-tillage (0.49), the manure-based (0.60), and the crownvetch systems (0.76). According to Table 3b, the crownvetch system had the smallest variability for wheat yield followed by the no-tillage and manure-based systems, as measured by the coefficient of variation.

Soybean yields were not analyzed here because no soybeans were harvested from the manure system in 1994 due to excess competition from weeds and no double-cropped soybeans were harvested in 1997 because of drought. However, the costs for growing soybeans were included in the economic analysis.

Economic Analysis

Table 4 shows total returns, variable costs, and gross margins for 1996, block 1. This Table represents one of the 16 tables with one table for each block and each year. We assume that both years of the rotation are represented in a hectare and thus the returns by crop shown in the Table are for a

TABLE 4. Costs, returns, and gross margins, 1996, Block 1.

	No-tillage	Crown vetch	Cover crop	Manure
RETURNS (per ha)				
Corn	441.39	592.19	402.36	234.54
Winter wheat	235.27	249.69	0.00	177.73
Wheat straw	109.28	89.89	0.00	61.22
Soybean	201.11	244.57	497.67	235.20
Total Returns	$987.06	$1,176.35	$900.03	$708.69
VARIABLE COSTS (per ha)				
Seeds	85.46	85.46	100.80	124.34
Fertilizers	150.37	145.02	89.68	0.00
Chemicals	126.57	135.50	59.63	0.00
Custom hire	340.33	380.41	298.18	424.28
Operating interest (12% p.a.)	63.91	66.74	47.90	40.38
Total Variable Costs	$766.63	$813.12	$596.19	$589.00
TOTAL GROSS MARGIN ($/ha)	$220.43	$363.23	$303.83	$119.69

half hectare. Total returns are simply the sum of returns of the individual crops. Gross margin is the total returns less total variable costs.

Gross margins for the four cropping systems from 1994 to 1997 are summarized in Table 5. For the average of four years, the cover crop system provides the greatest gross margins ($238.28 ha^{-1}), partly because of the highest average corn yields, followed by the no-till system ($233.27) and the manure-based system ($217.35 ha^{-1}). The average gross margin for the crownvetch system is the lowest ($53.34 ha^{-1}).

The manure-based system returned more gross margins than all other systems during 1994 and 1995 but had the smallest gross margins during 1996 and 1997. Poor crop yields in the last two years due to increased weed competition contributed to smaller gross margins. The manure-based system could become more profitable relative to the other three systems if weeds could be controlled. Also, the manure-based system has the potential to become the most profitable of the four systems, since its crops can be certified as organic and sold at premium prices.

Risk Analysis

Farming is a risky business, and farmers are constantly facing uncertainty due to unpredictable factors such as price variability, weather, diseases, pests, etc. Generally, farmers want to select a cropping system that generates the largest profits, but the variability of profits, or economic risks, can also affect the desirability of the cropping system. Farmers respond to risks in different ways. A risk neutral farmer will select the cropping system that generates the

TABLE 5. Gross margins, coefficients of variation, and safety-first lower limits.

		1994	1995	1996	1997	Mean	C.V.	Lower Limit
		$/ha	$/ha	$/ha	$/ha	$/ha		$/ha
No-tillage	1	307.97	214.15	220.43	−259.16	120.85		
	2	555.64	355.62	500.56	−57.18	338.66		
	3	491.49	328.58	284.57	−188.19	229.12		
	4	356.66	275.92	444.04	−98.81	244.45		
	Mean	427.94	293.57	362.40	−150.83	233.27	1.14	53.31
Crown vetch	1	−40.36	−139.74	363.23	−229.07	−11.49		
	2	−32.14	−149.98	470.86	−203.76	21.24		
	3	131.77	−29.81	552.20	−177.40	119.19		
	4	14.36	0.86	479.05	−156.59	84.42		
	Mean	18.41	−79.67	466.33	−191.71	53.34	5.45	−142.54
Cover crop	1	430.47	216.40	303.83	39.43	140.63		
	2	569.50	233.34	517.95	−103.95	304.21		
	3	528.46	229.54	434.65	−97.98	273.67		
	4	439.37	−1.88	404.93	−331.53	127.72		
	Mean	491.95	169.35	415.34	−123.51	238.28	1.24	39.21
Manure	1	391.19	320.51	119.69	−248.99	145.60		
	2	458.05	374.49	207.45	−285.20	188.70		
	3	580.20	530.05	225.72	−189.54	286.61		
	4	612.13	507.46	124.70	−250.24	248.51		
	Mean	510.39	433.13	169.39	−243.49	217.35	1.58	−14.38

largest expected (or average) profit without regard to variability of profits. In this study, a risk neutral farmer would prefer the cover crop system, since it generates the largest average gross margin of the four systems evaluated. Alternatively, a risk averse farmer is more concerned with the variability of profits and would be willing to sacrifice higher profits to achieve more stable profits. Table 5, column 8, shows the coefficients of variation for the four cropping systems. The no-tillage system provides the smallest coefficient of variation (1.14) followed by the cover crop system (1.24), the manure-based system (1.58), and the crownvetch system (5.45).

Another way to evaluate risks is the safety-first criterion (Musser et al., 1981; Hanson et al., 1993). This method is consistent with maximizing expected profits, where profits are used as a proxy for utility (Selley, 1984). The coefficient of variation measures the extent that profits deviate from the mean, both upward and downward. However, farmers are concerned about the downward deviations and not the upward deviations. The safety-first criterion assumes that the decision maker wants to maximize profits subject to the probability that profits will be greater than a specified disaster level. For empirical applications, the lower confidence limit of profits has been used to specify the disaster level. The lower confidence limit of profits for a particular activity, the ith cropping system in this case, can be calculated as

$$L_i = E_i - K\sigma_i$$

where

E_i = expected profits

K = the number of standard deviations required to impose the desired probability that E_i is greater than L_i

σ_i = the standard deviation of profits for activity i.

Assume that profits are normally distributed. For $K = 0.6745$ in a normal distribution, the probability that gross margins will be greater than or less than $K\sigma_i$ from the mean is 50 percent. That is, the probability that the gross margin will be below $L_i = E_i - K\sigma_i$ is 25 percent and the probability that the gross margin will be above $U_i = E_i + K\sigma_i$ is 25 percent (where U_i is the upper confidence limit). Farmers are only concerned with the lower limit. Thus, the farmer can expect to have profits at least $\$L_i$ in three out of four years. For example, the mean and standard deviation of gross margins for the no-tillage system are \$233.67 ha^{-1} and \$267.00 ha^{-1}, respectively. At the 75 percent confidence interval, the lower confidence limit for the no-tillage system is \$53.31 ha^{-1}. That means the farmers can expect to receive a gross margin of at least \$53.31 ha^{-1} in three out of four years using the no-tillage system.

The last column of Table 5 shows the lower limits of gross margins at the 75% risk confidence level for the four cropping systems. These results support the previous results using the coefficients of variation in that the no-tillage system has the smallest risks. Three out of four years, the average gross margins for the no-tillage system are expected to exceed \$53.31 ha^{-1} as indicated above. The cover crop system has the second smallest risks with the lower confidence limit of \$39.21 ha^{-1}, followed by the manure-based system with a −\$14.38 ha^{-1} lower confidence limit. Crownvetch has the largest risks with the confidence limit of −\$142.54 ha^{-1}.

The risks measured for the 1994-1997 period probably overestimated the variability of crop yields in the Mid-Atlantic states. Weather conditions during this period were the extremely variable, ranging from unusually good years in 1994 and 1996 to an extremely dry year in 1997. Therefore, results of economic and risk analyses based on the four years of yield data can not be considered "typical" or "representative." Different ranking of profits and risks could emerge for a typical or representative year. More data are needed to assess long-term profitability and risks.

Sensitivity Analysis

The relative profitability of the four cropping systems depends on relative prices, especially the input prices. The four systems use different sources of nitrogen. The no-tillage and crownvetch systems use chemical fertilizers, the cover crop system uses hairy vetch, and the manure-based system uses ani-

mal and green manures. We evaluated the impacts of changes in relative prices on the relative profitability of these three systems. The crownvetch system was not included in the comparison because it is the least attractive in terms of profitability and risks, and changes in relative prices would not make it more attractive than the other cropping systems.

The cover crop system, the most profitable of the four systems, uses hairy vetch as a major source of nitrogen. Recently, the prices of hairy vetch seeds have been quite variable, and farmers are concerned about their cost. Since the cost of hairy vetch seeds constitutes only a small part of the total costs (2.7 percent in 1996), changes in their prices are not likely to affect the ranking of profitability.

The no-tillage system, the second most profitable system, uses chemical fertilizers. The average price for nitrogen fertilizer in 1993 dollars from 1989 through 1996 was 54 cents kg^{-1} with a standard deviation of 6 cents kg^{-1}. Nitrogen fertilizer prices have been trending upward in recent years. Assume the trend will continue. If the nitrogen (N) fertilizer price increases one standard deviation (6 cents kg^{-1}) and prices of phosphorus (P) and potash (K) also increase proportionally, that is, the prices of N, P, and K increase from 55, 55, and 35 cents kg^{-1}, respectively, to 60, 60, and 38.85 cents kg^{-1}, the no-tillage system is still more profitable than the manure-based system, which ranks third in profitability. Prices for N, P, and K would have to increase by 12 percent to 61.6, 61.6, and 38.8 cents kg^{-1}, respectively, to make the manure-based system more profitable than the no-tillage system. Since the no-tillage system also uses herbicides to control weeds, increases in both fertilizer and herbicide prices of less than 12 percent will make the manure-based system more profitable.

The manure-based system derives plant nutrients from animal and green manures and does not use commercial fertilizers and chemicals. It is an organic farming system. The costs for using animal manures include processing, storage, transportation, field applications, and purchasing of manures. The cost for purchasing animal manures can be negative if livestock producers have excess manures to dispose of and pay crop growers to haul away the manures. The cost of transportation is a dominant factor. It depends on the water content of the animal manures, the hauling distance from a storage site to the application field, and the number of trips required to supply the amount of manures needed to provide enough nutrients for crop growth. Thus, the costs of animal manure application can vary considerably from farm to farm. If livestock farmers subsidize crop growers for using manures, and the costs of animal manure application dropped from \$2.21 MT^{-1} to less than \$1.10 MT^{-1}, the manure-based system will become most profitable.

Since the manure-based system is an organic system, its crops can be certified as organic and sold at premium prices. Premium prices would only need to be 3.5 percent higher than prices for conventional crops for the manure-based system to be the most profitable of the four systems evaluated.

CONCLUSIONS

This paper evaluates the profitability and economic risk associated with four cropping systems established at the Sustainable Agriculture Demonstration site of the Beltsville Agricultural Research Center in Beltsville, Maryland, for the period 1994 through 1997. The four cropping systems are: (1) a *no-tillage system* with recommended fertilizer and herbicide inputs, (2) a no-tillage system with a *crownvetch* living mulch suppressed with herbicides, (3) a no-tillage system with winter wheat and hairy vetch *cover crops*; and (4) a minimum tillage *manure-based system* in which no chemicals are applied and animal and green manure is incorporated using a chisel plow. Each system is a two-year rotation with corn planted in the first year and winter wheat and soybeans planted in the second year. In the cover crop system, hairy vetch is grown as a cover crop before corn planting and winter wheat is treated as a cover crop before soybean planting. Winter wheat is harvested as a feed grain crop in the other three systems. Crimson clover is overseeded into soybeans as a green manure crop for corn in the manure strategy.

Yield variability is a major consideration when evaluating alternative farming systems that reduce the potential for soil erosion on sloping lands. Corn is the primary crop in all four cropping systems evaluated at the Sustainable Agriculture Demonstration site. Average corn yields were greatest for the cover crop system followed by the no-tillage, crownvetch, and manure-based systems. The relative variability of corn yields when measured by the coefficient of variation was smallest for the cover crop system, followed by the no-tillage system, the manure-based system, and the crownvetch system. Hanson et al. (1993), and Ott and Hargrove (1989) report similar findings for no-tillage corn systems with hairy vetch as the cover crop. Hanson et al. (1993) reports that hairy vetch acts as a yield enhancer for no-tillage corn rather than a nitrogen substitute.

Profitability and economic risk are also major concerns for farmers when evaluating the sustainability of cropping systems integrating both minimum tillage with cover crops. The results of our analysis indicate the cover crop system produces the largest average gross margin, followed by the no-tillage, manure-based, and the crownvetch systems. Again, these results are similar to those reported by Hanson et al. (1993) and Ott and Hargrove (1989), where no-tillage/hairy vetch corn systems were found to produce larger average returns than most other corn systems. However, in terms of economic risk, the no-tillage system is the preferred system for risk avert farmers when evaluated by both coefficient of variation and safety-first criteria. The cover

crop system is second best in terms of economic risk, followed by the manure-based and crownvetch systems. These results differ from those reported by Hanson et al. (1993) and Ott and Hargrove (1989), where corn and hairy vetch cover crop systems were found to be preferred by risk-averse farmers in most instances. A likely reason for the different economic risk findings is that the cropping systems in our study harvest soybeans and winter wheat also, whereas Hanson et al. (1993) and Ott and Hargrove (1989) focus on monocropped corn with cover crops grown between corn harvest and planting.

Several key points and limitations need to be mentioned in order to properly interpret the results of this study. First, weather conditions during the 1994-1997 period were extremely unusual and thus the results of the economic and risk analyses based on the four years of yield data can not be considered "typical" or "representative." More data are needed to assess long-term profitability and risks. In a separate paper, we will use a simulation model to evaluate the four cropping systems studied in this paper along with other systems under different weather conditions.

Second, the results of our study may be considered applicable to the mid-Atlantic and Southeastern states of the U.S. due to the cover crops evaluated. Legume crops such as hairy vetch and crimson clover preform poorly in cold environments. Low winter temperatures less than $-15°C$ can reduce or eliminate the legume stand (Allison and Ott, 1987). Consequently, cropping systems with hairy vetch or crimson clover may be inappropriate for some northern regions of the U.S. Also legume cover crops may reduce soil moisture in the spring and may leave insufficient moisture to adequately germinate grain crops during dry weather conditions (Allison and Ott, 1987). Thus, cropping systems with legume cover crops may be inappropriate for some western regions of the U.S. where winter fallow is practiced to conserve soil moisture in rain-fed agriculture.

Finally, environmental impacts of these systems were not evaluated in this study. Other long-term objectives such as reduced soil erosion, reduced fertilizer losses, and reduced pesticide hazards must be considered along with profitability and economic risk when identifying sustainable agricultural cropping systems. These objectives are often in conflict with one another (Kelly et al., 1996). Future research will take these objectives into account.

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